Guidelines for Assessment and Evaluation of Engineering and Engineering Technology Programs

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Background

The TAC/ABET (Technology Accreditation Commission/Accreditation Board for Engineering and Technology) criteria[1] for accrediting engineering technology programs and EAC/ABET (Engineering Accreditation Commission/Accreditation Board for Engineering and Technology) criteria[2] for accrediting engineering programs require programs to demonstrate that specific outcomes are achieved by students and objectives of a program are achieved. These criteria for accrediting engineering technology programs are known as the TC2K Criteria and are now applicable to all engineering technology programs seeking TAC/ABET accreditation. The EAC/ABET criteria for accrediting engineering programs, known as E2K criteria, also require engineering programs to demonstrate that students attain such outcomes and programs achieve their objectives. In general, the outcomes are typically demonstrated by the student and measured by the program at the time of graduation. Program objectives relate to performance of graduates a few years after graduation. This paper provides guidelines for assessing and evaluating engineering and engineering technology programs.

The intent of the above criteria is that a continuous improvement process[1](CIP) must form the foundation of assessment and evaluation of engineering and engineering technology programs as shown in Figure 1. This process approach will facilitate attainment of desired objectives and outcomes by managing activities and related resources as a process. The "process approach" is a generic management principle, which can enhance an organization's effectiveness and efficiency in achieving defined objectives and outcomes. A popular continuous improvement process is characterized via the PDCA (Plan-Do-Check-Act) cycle[2]. This PDCA cycle is recommended for continuous assessment, evaluation and improvement of a program in this paper even though the process improvement method of the six-sigma approach or the eight-discipline (8-D) method commonly used by automotive industry may also be applied.

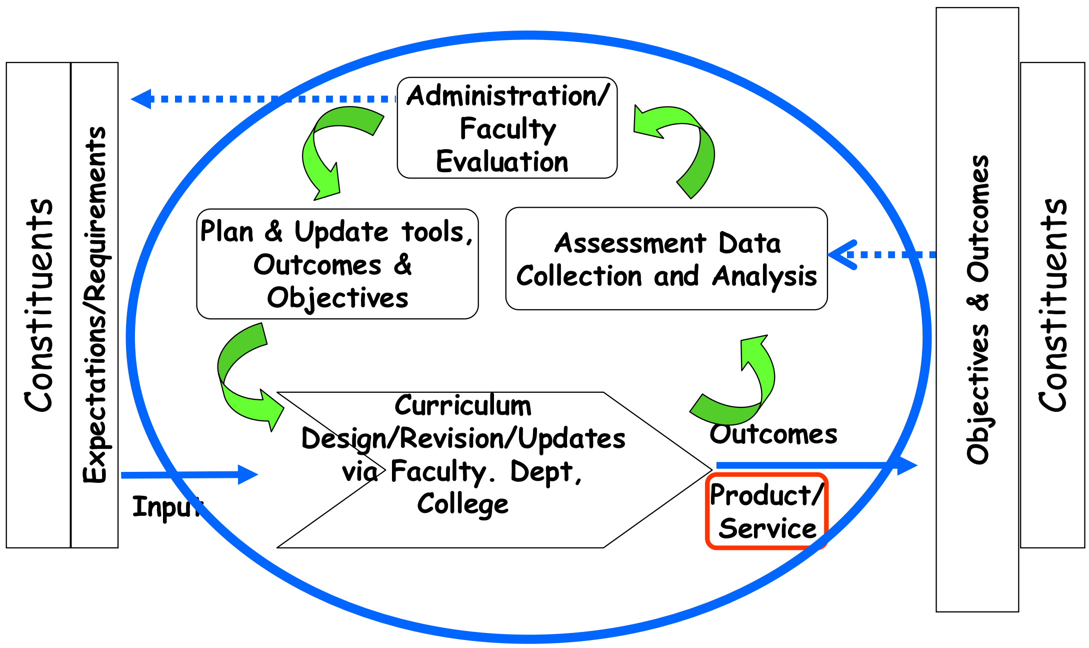

Figure 1: Continuous Improvement Process

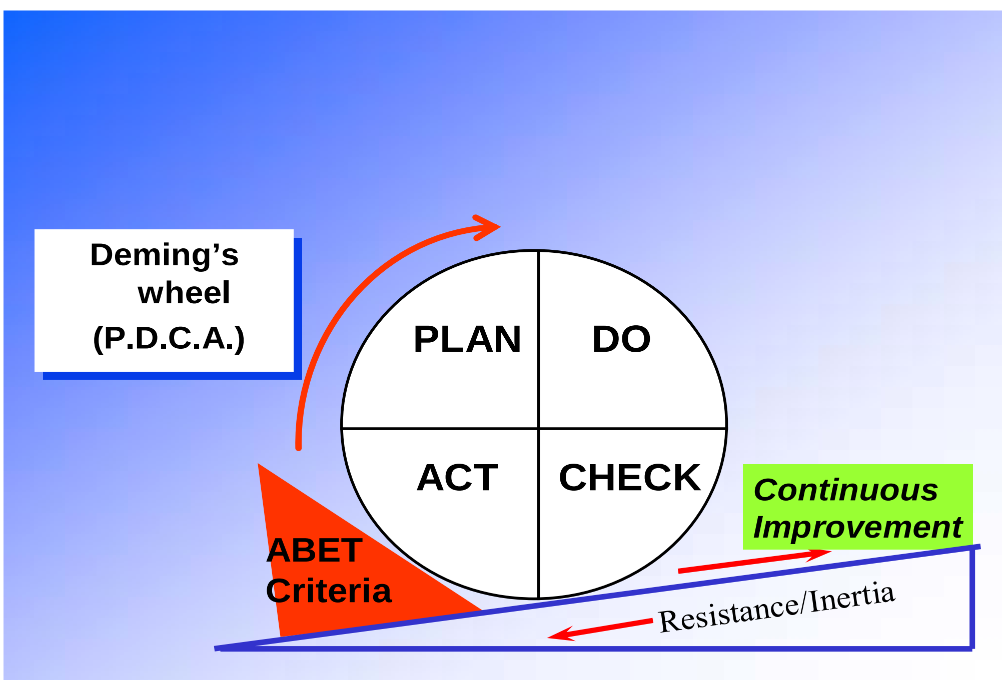

Figure 2: ABET Criteria & PDCA Assist in Continuous Improvement.

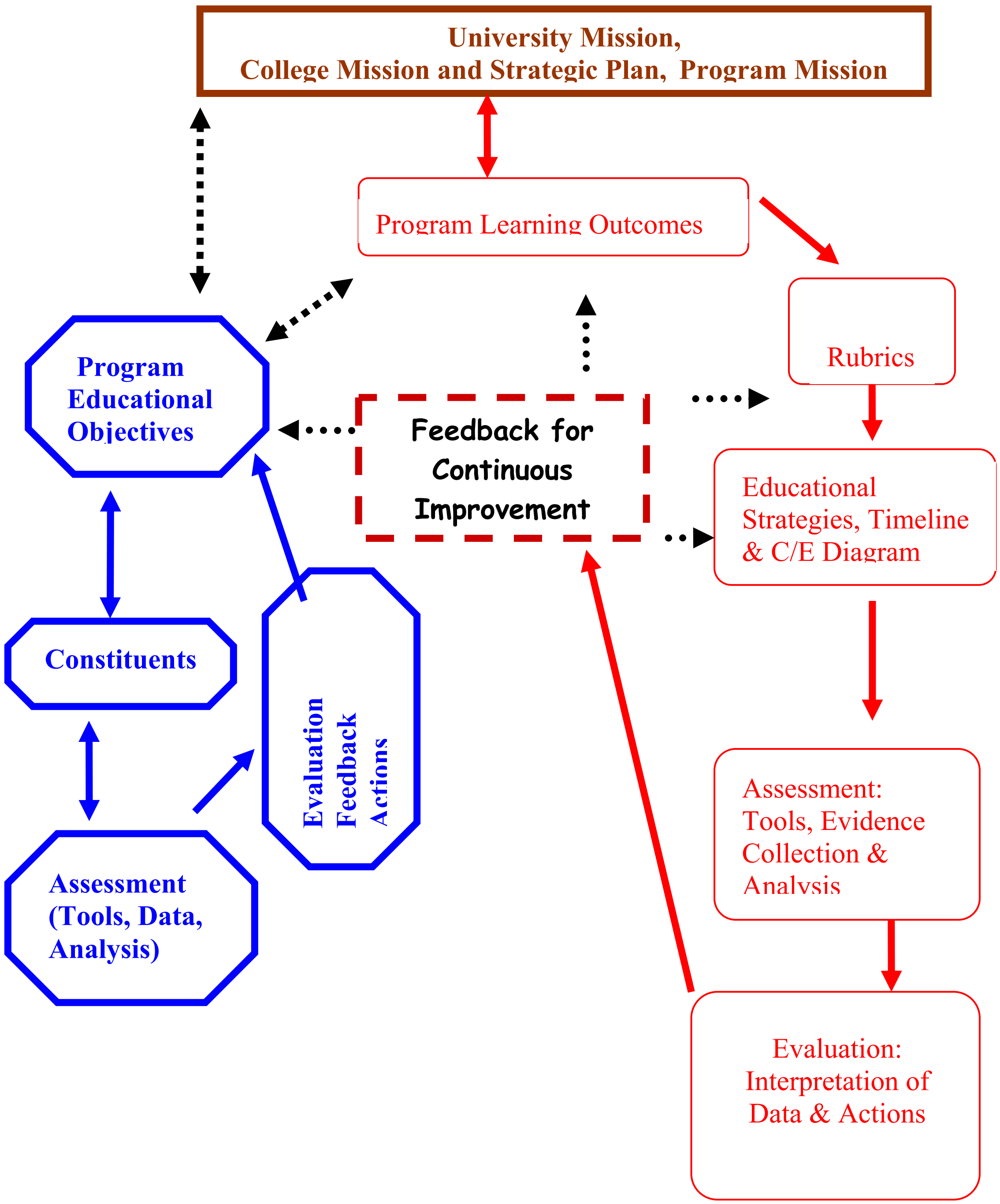

Figure 3: Two Assessment and Evaluation Loops

The PDCA cycle is an established and logical method that can be used to improve a process. This requires:

(P) Planning (what to do and how to do it),
(D) Executing the plan (do what was planned),
(C) Checking the results (did things happened according to plan) and
(A) Acting to improve the process (how to improve next time).

The PDCA cycle can be applied within an individual process, or across a group of processes. This paper provides details about assessment, evaluation, and improvement of a program using this cycle. Specifically, this paper lists ideas for multiple assessment tools to be considered in the planning phase and administered in the second phase. In addition, the paper shows how the collected assessment data may be interpreted in the third step to form the basis for decisions and actions in the last phase of the cycle.

The ABET criteria and PDCA cycle may be viewed together as depicted in Figure 2. In every system and process there is sufficient inertia to let a status quo prevail and complacency to creep in. However, the PDCA cycle forces a program and its faculty to strive for continuous improvement of the curriculum instead of attempting to ride on past successes. The ABET criteria assist faculty in holding on to the gains in achieving the desired objectives and outcomes and also in attempting to make significant gains in the future.

As shown in Figure 3, two separate and distinct feedback loops[3] are necessary to continuously improve a program. One of the loops in Figure 3 deals with program objectives and the other loop deals with program outcomes. The specifics details of these loops and respective assessment plan and evaluation procedures may be developed by faculty with input from alumni, employers, national and local conferences, colleagues at other universities, published literature, program evaluators and commissioners of ABET, Inc. and the other interested constituents. Figure 3 provides a basis for obtaining feedback on the program, its outcomes, and its objectives, and using that feedback for making improvements.

Assessing Current Program Status

Faculty in a program must first assess the current state of the assessment and evaluation process. Table 1 is recommended for this self assessment and it is a modified version of the one proposed by Gloria M. Rogers, Rose-Hulman Institute of Technology in 2004. Faculty discussions while completing the self assessment using Table 1 will prove to be valuable in developing an overall process for assessment and evaluation of programs. For example, this self assessment requires stakeholders of a program to be identified and listed. In addition, it requires program objectives to be linked to university and college missions and leads to development of matrices to portray these linkages. Finally, the self assessment table ensures that critical aspects of assessment and evaluation of outcomes such as developing manageable program outcomes, linking them to program objectives, aligning them with the college mission, selecting multiple assessment tools, reviewing of assessment data, taking actions to improve program, etc are executed continuously as per the PDCA cycle. Use of this self assessment table will allow programs to eliminate deficiencies and weaknesses in the formal ABET review.

Table 1: Self-Assessment* of Assessment and Evaluation of Program Objectives and Outcomes[3]

0-not in place; 1-beginning stage of development; 2-beginning stage of implementation; 3-in place and implemented;
4-implemented and evaluated for effectiveness; 5-implemented, evaluated and at least one cycle of improvement

Stakeholder Involvement (Those who have a vested interest in program success)	RATING	**Performance Objectives** (Graduate's performance 3-5 years after completing program)	RATING	**Learning Outcomes** (desired knowledge, skills, attitudes, behaviors at graduation)	RATING	Outcomes aligned with educational practice	RATING	Program and/or Institutional Assessment	RATING	Evaluation	RATING
Stakeholders are identified	5	Objectives are defined	5	Outcomes are identified	5	Desired outcomes are mapped to educational practices and/or strategies	5	Assessment is systematic at the program/ institutional level	4	Assessment data are systematically reviewed	5
Primary stakeholders are involved in identifying educational objectives	5	Stakeholders provide input to development of objectives	5	Number of outcomes are manageable	5	Outcomes are mapped to both curricular and co-curricular activities	5	Multiple methods are used to measure each outcome	5	Evaluation of results are done by those who can effect change	5
Primary stakeholders are involved in periodic evaluation of educational objectives	5	Number of objectives is manageable	5	Outcomes are publicly documented	3	Practices/strategies are systematically evaluated using assessment data	5	Both direct and indirect measures of student learning are used to measure outcomes	5	Evaluation of assessment data is linked to practices	5
Sustained partnerships with stakeholders are developed	5	Objectives are aligned with mission	5	Outcomes are linked to performance objectives	5	Educational practices are modified based on evaluation of assessment data	5	Assessment processes are reviewed for effectiveness and efficiency	5	Evaluation leads to action	5
		Objectives are periodically assessed	5	Outcomes are defined by a manageable number of measurable performance indicators	5			Assessment methods are modified based on evaluation processes	5		
		Objectives are periodically evaluated for relevancy	5	Outcomes are aligned with mission	5						

*2004 Gloria M. Rogers, Rose-Hulman Institute of Technology (gloria.rogers@rose-hulman.edu)

Program Objectives

Program objectives identify the skills and abilities graduates are expected to demonstrate a few years after graduation. Before developing program objectives, program faculty must list primary constituents or stakeholders of the program. These primary constituents may be identified from the mission statement of the university and college. Stakeholders may include alumni, current students, potential future students, legislators, local citizens, students, faculty, parents, graduate schools, and industry or industrial advisory board members. For a new program or a program planning to revise its objectives, the stakeholders may be ranked in the order of easy accessibility and fast response to requests from the program. It is not necessary for all stakeholders to be consulted each year, but a program must have a plan to seek input from its stakeholders periodically. Frequency of contact for each stakeholder group may be defined. For example, each year a program may poll its two-year and five year alumni. See Table 2 for a summary of assessment tools and frequency of use. It is recommended that a program have about five to seven objectives covering technical competence, professional growth (leadership, communication, and team work), global awareness, and responsible citizenship. Finally program faculty must develop the following matrices to establish that the program objectives were developed by taking into account the institutional culture.

1. Matrix linking program objectives to university mission
2. Matrix linking program objectives to college mission and/or strategic plan
3. Matrix linking program objectives to program outcomes

The objectives must be published in several places including the University Catalog, fact sheets, the curriculum sheets, course syllabi, instructions provided to students on preparation of a student portfolio, and survey forms used to solicit feedback from program's various constituents.

Program Outcomes

The outcomes are abilities, skills, awareness, knowledge, and understandings that must be inculcated in students in various courses in the curriculum. Faculty members must design course activities to foster the achievement these outcomes so that graduates of the program will be able to demonstrate the achievement these via accumulated course activities. The program outcomes must be linked to program objectives as stated in the previous section and also outcomes (a) through (k) specified in applicable ABET criteria. For example, program outcomes may be defined under the following five broad categories of Foundation, Communication, Responsibility Problem Solving Skills, and Growth and these may be linked to outcomes (a) through (k) specified in applicable ABET criteria as shown in Table 3. The depth of coverage of outcomes in various courses may be summarized using Table 4.

Rubrics may be developed and used to determine the degree to which program outcomes are attained in any course activity. Rubrics are systematic scoring methods that use pre-determined criteria. Rubrics may be *holistic* (score for entire work as a whole) or *analytic* (score for several distinct criteria). The use one rubric for each outcome is recommended so that student or target group development over a long time period may be tracked and compared. Rubrics make the assessment process very powerful and allow student achievement of outcomes to be analyzed in multiple ways over time. Table 5 provides rubrics for one specific outcome.

Table 2. Assessment Tools

ASSESSMENT TOOL	RESPONSIBILITY FOR ADMINISTRATION	SCHEDULE / FREQUENCY	ASSESSMENT DATA PREPARATION & EVALUATION PROCESS
1. Alumni Survey	Department Chair / Program Coordinator	January of each year Poll two-year alumni and five-year alumni.	Assessment of program objectives. Summer of each year Summarize assessment data in spreadsheet. Conduct test of hypothesis of fraction satisfied and mean score. Note extreme comments. Present findings, identify potential causes, and suggest actions to faculty. Apply the cause-effect diagrams to discuss action plan.
2. Employer Survey	Department Chair / Program Coordinator	January of each year. Poll employers of two-year alumni and five-year alumni.	Assessment of program objectives. Summer of each year Summarize assessment data in spreadsheet. Conduct test of hypothesis of fraction satisfied and mean score. Note extreme comments. Present findings, identify potential causes, and suggest actions to faculty. Apply the cause-effect diagrams to discuss action plan.
3. Graduate Exit Questionnaire	College /Department Chair/Program Coordinator	Last week of classes each semester in the senior design course	Assessment of program outcomes. Summarize assessment data in spreadsheet. Conduct test of hypothesis of fraction satisfied and mean score. Note extreme comments. Present findings, identify potential causes, and suggest actions to faculty. Apply the cause-effect diagrams to discuss action plan.
4. Statistical Data			
(a) Fundamentals of Engineering (FE) Examination Results	College	Each semester when FE examination are provided by NCEES (National Council of Examiners for Engineering and Surveying)	Assessment of program outcomes. Compute passing rate. Assess performance in each subject area. Present findings, identify potential causes, and suggest actions to faculty. Apply the cause-effect diagrams to discuss action plan.
(b) Placement Statistics	Career Center	Each year.	Assessment of program outcomes. Analyze placement and starting salaries.

(c) Cooperative Education positions and summer internships	Department Chair / Program Coordinator	Each semester	Assessment of program outcomes. Compute percentage of graduates who had Cooperative Education positions and summer internships. Identify potential causes, and suggest actions to be taken by faculty in advising sessions.
5. Industrial Project Sponsor Survey	Courses where industry sponsored design projects were used.	Each semester at the final presentation of the project report to the industry.	Assessment of program outcomes. Summarize assessment data in spreadsheet. Conduct test of hypothesis of fraction satisfied and mean score. Note extreme comments. Identify potential causes and suggest actions to faculty.
6. Employer Assessment of Academic Preparation	College, Director of Cooperative Education Program	Last month of cooperative education or summer internship position.	Assessment of program outcomes. Summarize assessment data in spreadsheet. Conduct test of hypothesis of fraction satisfied and mean score. Note severe comments. Present findings, identify potential causes, and suggest actions to faculty. Apply the cause-effect diagrams to discuss action plan.
7. Student Portfolio	Department Chair / Program Coordinator & faculty.	Each semester.	Present findings, identify potential causes, and suggest actions to faculty. Apply the cause-effect diagrams to discuss action plan.
8. Direct Measurement of outcomes in courses.	Course folders/binders	Frequency depends on the outcome and faculty member.	Faculty members present their data at faculty meeting in January and September for the previous semester or year.
9. University Self-Study and Review.	Department Chair / Program Coordinator	Once in five years.	
10. ABET/EAC Review	Department Chair / Program Coordinator & faculty members.	Frequency depends on the final accreditation action by ABET/EAC.	
11. College of EMS Advisory Board & Alumni Board	Department Chair / Program Coordinator/ Faculty Volunteer	Once every year, but consolidated every three years into action items	Major revisions and improvements are presented and feedback is used by faculty.

Table 3: Relationship between Program Outcomes and ABET/EAC Outcomes

ABET Outcome/ Graduate Expectation	Program Outcomes				
	1 Foundation	2 Communication	3 Responsibility	4 Problem Solving	5 Growth
a	●			●	
b	●			●	
c	●			●	
d		●		●	
e	●			●	
f			●		●
g		●		●	
h			●		●
i			●		●
j	●			●	●
k	●			●	

Table 4: Outcomes in courses: I-Introductory, E-Emphasis, and R-Reinforcement

Course Number	Industrial Engineering Program Outcomes				
	1 Foundation	2 Communication	3 Responsibility	4 Design	5 Growth
Required					
Course XXX1	I	I	I	I	I
Course XXX2	E	E	E	E	E
Course XXX3	R	R	R	R	R

The type and depth of coverage of program outcomes in courses are classified as introductory (I), emphasis (E), or reinforcement (R) in Table 4. The introductory coverage assumes that students do not have the ability, skill, understanding, or knowledge of the topic or its importance.

Table 5: Rubrics for Outcome: An understanding of professional and ethical responsibility.

Metric & Weight (W)	**Unacceptable (Score, S=0)**	**Marginal (Score, S=1)**	**Acceptable (Score, S=2)**	**Exceptional (Score, S=3)**	**Points (P)** **P = W*S**
Knowledge of Professional Code of Ethics **(W=1)**	Feels that code of ethics of professional societies irrelevant. Has read, but does not remember professional code of ethics.	Knows about code of ethics of professional societies, but will access and use them when ethical problems are faced.	Knows where to access code of ethics of at least 1 professional society. Has read and demonstrated adequate knowledge of at least one professional code of ethics.	Knows where to access code of ethics of 2 or more professional societies. Has read and demonstrated excellent knowledge of at least one professional code of ethics.	
Knowledge of Theories of Ethics (W=1)	Considers theories of ethics to be of no value.	Knows one theory of ethics that will be useful personally.	Remembers a few theories of ethics.	Excellent knowledge of all theories of ethics.	
Ability to Recognize Ethical Dilemmas (W=1)	Does not wish to apply the code of ethics from professional societies and/or ethical theories.	Will learn to apply the code of ethics from professional societies and/or ethical theories to recognize ethical dilemmas when necessary.	Can apply at least 1 code of ethics from professional societies and/or ethical theories to recognize ethical dilemmas and analyze them.	Can apply the code of ethics from professional societies and/or ethical theories to recognize ethical dilemmas and analyze them in many ways.	
Analyze Ethical Problems in Work and Make Decisions (W=1)	Feels that ethical problems in IE work will be rare. Does not wish to waste time now with case studies.	Has ability to analyze ethical problems in work through case studies, but is not interested. Has generated fair solutions and made fair decisions in the IE field.	Has demonstrated good ability to analyze ethical problems in work through case studies. Has generated good solutions and made good decisions in the field.	Has demonstrated excellent ability to analyze ethical problems in work through case studies. Has generated excellent solutions and made sound decisions in the field.	
Total Points (TP=ΣP)					

Overall Performance Criterion: TP≥7	**Unacceptable 0≤TP≤3**	**Marginal 4≤TP≤6**	**Acceptable 7≤TP≤11**	**Exceptional TP=12**

Instruction is focused on introducing students to the respective outcome, providing meaningful course activities to make them recognize its importance, and motivating them to enhance the ability or understanding in the next upper level course. Emphasis on program outcomes in some courses is via open ended course activities, literature search, team projects, case studies, group discussions, etc that are designed provide opportunities for students to explore and enhance their competencies. Reinforcement of program outcomes is mostly achieved in upper level courses. Students are assumed to possess reasonable knowledge, understanding, skill, or ability to apply their competency to analyze a problem, case study, situation, or industrial project. Instructional activity continues to build upon previous competency and reinforces content/skill competency. It may be a good idea to map ABET outcomes (a) through (k) to activities and work in each course.

Assessment Data Analysis

Assessment data collected using various tools may be summarized in a spreadsheet so that many statistical tools or statistical software can be used in the analysis. Faculty may take primary responsibility for entering summary of assessment data into spreadsheet, conducting analysis and arriving at interpretations. Further analysis and interpretation may take place at faculty meetings. Any comments, suggestions, and recommendations resulting from the evaluation process may be translated by faculty into actions via cause – effect diagrams similar to the one in Figure 4 at the end of this paper for not achieving EAC/ABET outcome 3(f)[4,5]. The actions may involve changes in teaching methods, course descriptions, assignments, laboratory projects, curriculum, etc. Changes may range from modifying the way a topic is covered in a course to addition and deletion of required courses.

Consider first the assessment data collected from Alumni Survey for achievement of program objectives and outcomes. Assume that each survey item had five response levels, namely, Strongly Agree, Agree, Neutral, Disagree, and Strongly Disagree. To perform statistical analysis of the data, numerical weights may be assigned the responses and these may be: Strongly Agree=5, Agree=4, Neutral=3, Disagree=2 and Strongly Disagree=1. A weighted average score of more than 3 is considered to be satisfactory attainment of the respective objective or outcome.

H0: Weighted average =3, i.e., outcome or objective is not achieved
H1: Weighted average >3, i.e., outcome or objective is achieved
Weighted average = Σ (# of responses for a category*respective weight) /Total responses

Normality of underlying distribution is assumed in this analysis and this may be appropriate because of the Central Limit Theorem. If the null hypothesis is rejected, it will imply that the respective outcome is or objective is achieved. In this test of hypothesis, Z = (Weighted Average – 3) / (Std. Dev/Sqrt(n)). The test of hypothesis is carried out for each objective and outcome using a level of significance of α =0.05.

Alternatively, the same alumni data may be analyzed using a test of hypothesis about attribute p which is defined as fraction of alumni satisfied with an outcome or objective. The corresponding test of hypothesis for each outcome and objective is:

H0: Fraction Satisfied = 0.6, i.e., outcome or objective is not achieved
H1: Fraction Satisfied > 0.6, i.e., outcome or objective is achieved

Fraction satisfied = (# Strongly Agree + Agree + Neutral)/Total Responses

Normality approximation to binomial distribution is assumed in this analysis. If the null hypothesis is rejected, it will imply that the respective outcome is achieved. In this test of hypothesis, Z or t = (p–0.6) /Sqrt(p(1-p)/n). The test of hypothesis is carried out for each objective and outcome using a level of significance of α =0.05. Bar graphs and other charts may also be used to summarize assessment data. A target value may be used to decide if an outcome or objective is achieved. Normality of data was verified using Minitab. All

Evaluation Actions and Conclusions

Evaluation of assessment data and actions taken to improve a program may be summarized using a table similar to Table 6 below. Normal plots of assessment data proved that the normality assumption was satisfied in each and every case. The final conclusion in the evaluation process was that all objectives and outcomes were achieved. However, analysis of raw assessment data revealed specific continuous improvement opportunities. The typical actions taken to improve the curriculum as listed below.

Table 6. Evaluation of Assessment Data and Actions

TOOL & YEAR	FINDING	POTENTIAL CAUSES	ACTION
Alumni Data Fall 2001, Spring 2002, F2004 & S2005	Failure to understand the effects that the products they develop will have on the environment.	The curriculum deals with management and production. Product design is not covered explicitly. Sample size may be too small to distort sample statistics or distributional assumptions may not be satisfied in the statistical tests used in analysis. Test statistic value may be very close to the critical value even though the null hypothesis was rejected and the failure to achieve the outcome was not very severe.	Life Cycle principles, life cycle costing, and life cycle management are being taught in courses. This concept is now introduced in course XXX1 and is emphasized, or reinforced in course XXX2. This action was taken in fall 2005 and is shown in minutes of faculty meetings. Cumulative assessment data from 2000 to 2005 does not show that this continues to be a problem. Finding is contradicted by the other test of hypothesis and may be a false-negative.
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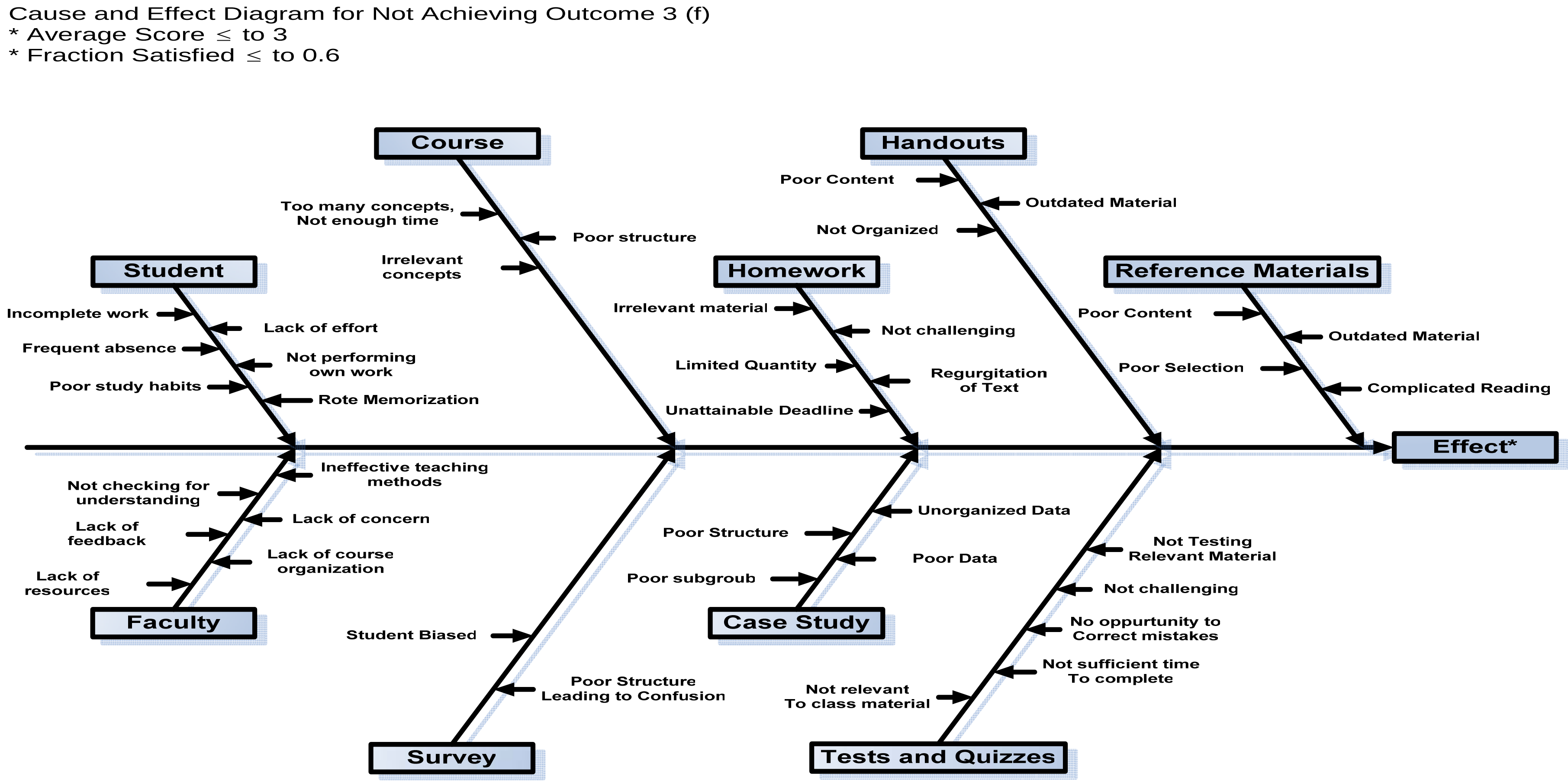

Figure 4: Cause – Effect Diagram for not Achieving EAC/ABET Outcome 3(f)

References

1. ISO 9000:2005, Quality management systems -- Fundamentals and vocabulary, International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, Case postale 56, CH-1211 Geneva 20, Switzerland.
2. Montgomery, D., Introduction to Statistical Quality Control, John Wiley, 2005.
3. Rogers, G., Assessment Planning Flow Chart, 5233 Wagon Shed Circle, Owings Mills, MD 21117, email: grogers@abet.org
4. CRITERIA FOR ACCREDITING ENGINEERING TECHNOLOY PROGRAMS, Effective for Evaluations During the 2007-2008 Accreditation Cycle. Incorporates all changes approved by the ABET Board of Directors as of October 28, 2006. Engineering Accreditation Commission. ABET, Inc. 111 Market Place, Suite 1050, Baltimore, MD 21202
5. CRITERIA FOR ACCREDITING ENGINEERING PROGRAMS, Effective for Evaluations During the 2007-2008 Accreditation Cycle. Incorporates all changes approved by the ABET Board of Directors as of October 28, 2006. Engineering Accreditation Commission. ABET, Inc. 111 Market Place, Suite 1050, Baltimore, MD 21202

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